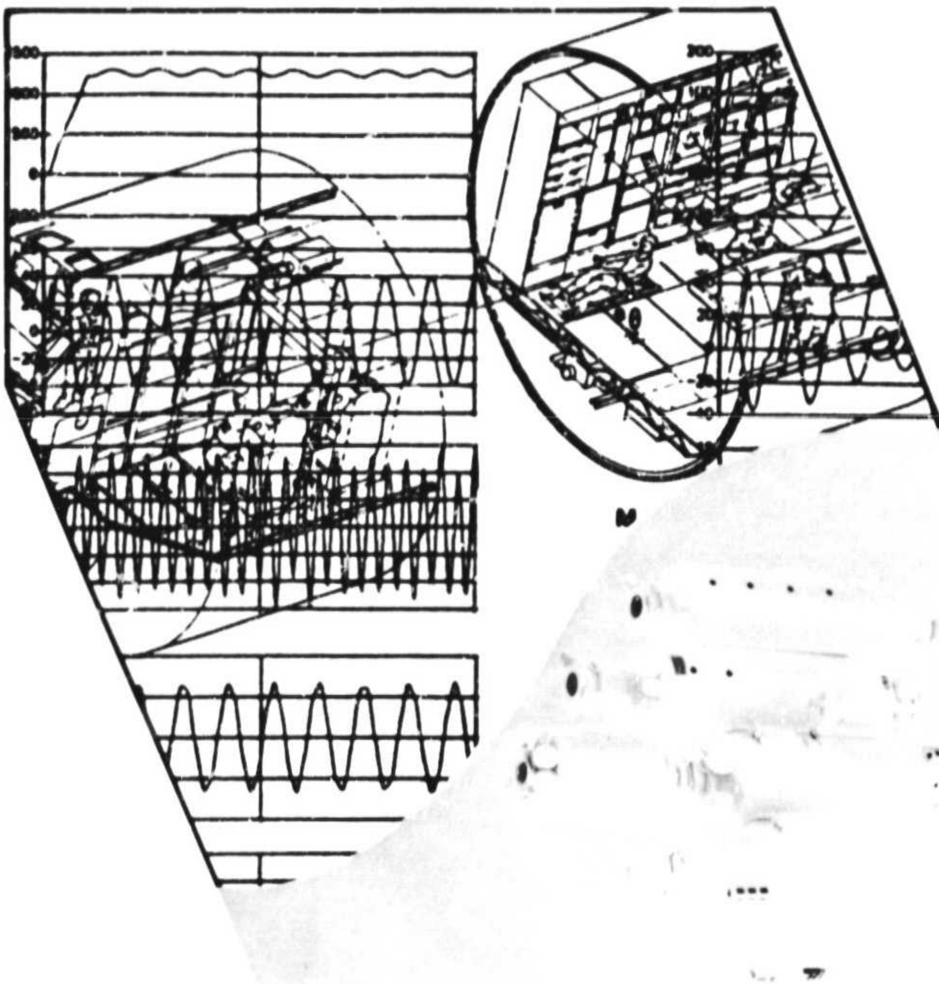
Final Report Volume III
Technology Advancement
Program Plan
D483-10012-3

Space Station Systems Technology Study

(Add-on Task)



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SPECTRA RESEARCH SYSTEMS (SRS)

SPACE STATION SYSTEMS TECHNOLOGY STUDY
(ADD-ON TASK)

Final Report

VOLUME III

TECHNOLOGY ADVANCEMENT PROGRAM PLAN

D483-10012-3

Conducted for NASA Marshall Space Flight Center

Under Contrcct Number NAS8-34893

February 1985

Boeing Aerospace Company

Spectra Research Systems

FOREWORD

The Space Station Systems Technology Study (Contract NAS8-34893 S/A 6) was initiated in June 1984 and to be completed in February 1985. The study was conducted for the National Aeronautics and Space Adminstration, Marshall Space Flight Center, by the Boeing Aerospace Company with Spectra Research Systems as a subcontractor. The study final report is documented in three volumes.

D483-10012-1 Vol. I	Executive Summary
D483-10012-2 Vol. II	Trade Study and Technology Selection Technical Report
D483-10012-3 Vol. III	Technology Advancement Program Plan

Mr. Robert F. Nixon was the Contracting Officer's Representative and Study Technical Manager for the Marshall Space Flight Center. Dr. Richard L. Olson was the Boeing study manager with Mr. Paul Meyer as the technical leader and Mr. Rodney Bradford managed the Spectra Research Systems effort.

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LIST OF ACRONYMS AND ABBREVIATIONS

ATP	Authorization to Proceed
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CPU	Central Processing Unit
DMS	Data Management System
EC/LSS	Environmental Control/Life Support System
ES	Expert System
FAB	Fabrication
F/O	Fiber Optics
FY	Fiscal Year
GSFC	Goddard Space Flight Center
HOL	Higher Order Language
IC	Integrating Controller
IOC	Initial Operational Capability
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LAN	Local Area Network
LCLV	Liquid Crystal Light Valve
LeRC	Lewis Research Center
LED	Light Emitting Diode
LISP	List Processor
MBPS	Megabytes per Second
MHz	Megahertz
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NIU	Network Interface Unit
NOS	Network Operating System
NRZ	NonReturn to Zero
O&C	Operations and Check-Out
ROM	Read Only Memory
RTOP	Research Technology Objectives and Plans
SS	Space Station
STS	Space Transportation System

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

TCS	Thermal Control System
TDRSS	Tracking & Data Relay Satellite System
TMS	Teleoperator Maneuvering System

1.0 Introduction

This volume of the final report for the Space Station Systems Technology Study provides the technology advancement program plans for the critical or high priority technology items identified in the system trade studies in Volume II.

The flow diagram of Figure 1.0-1 shows an overview of the major technology definition tasks and subtasks with their interfaces and interrelationships. Although not specifically indicated on the diagram, iterations were required at many steps to finalize the results. The development of the integrated technology advancement plan was initiated with the results of the Advanced Platform System Technology Study (APSTS) and the results of two previous tasks in this study; i.e., the trade studies and the preliminary cost and schedule estimates for the selected technologies. Descriptions for the development of each viable technology advancement were drawn from the trade studies. Additionally, a logic flow diagram depicting the steps in developing each technology item was developed along with descriptions of each major element of that flow. Next, major elements were time-phased, allowing the definition of a development schedule consistent with the Space Station program when possible. Schedules show the major milestones of the development programs including test required as described in the logic flow diagrams. Cost and resource estimates were primarily based on experienced estimates made by the various subsystem experts with consideration drawn from the RCA Price hardware development cost modeling program. The results produced by the task are an advancement plan for each selected technology that reflects technology status and planning within NASA and industry. Consequently, an integrated technology advancement plan has been developed from the set of individual advancement plans and is provided in this volume.

Advancement program plans were developed for the following areas:

a. Integrating Controller for Space Station Autonomy

b. Controls and Displays

The plans are similar in format for each technology area and specific technology items within the areas. Each plan contains information on technical approach, facility requirements and candidate facilities, development schedules, and resource requirements estimates.

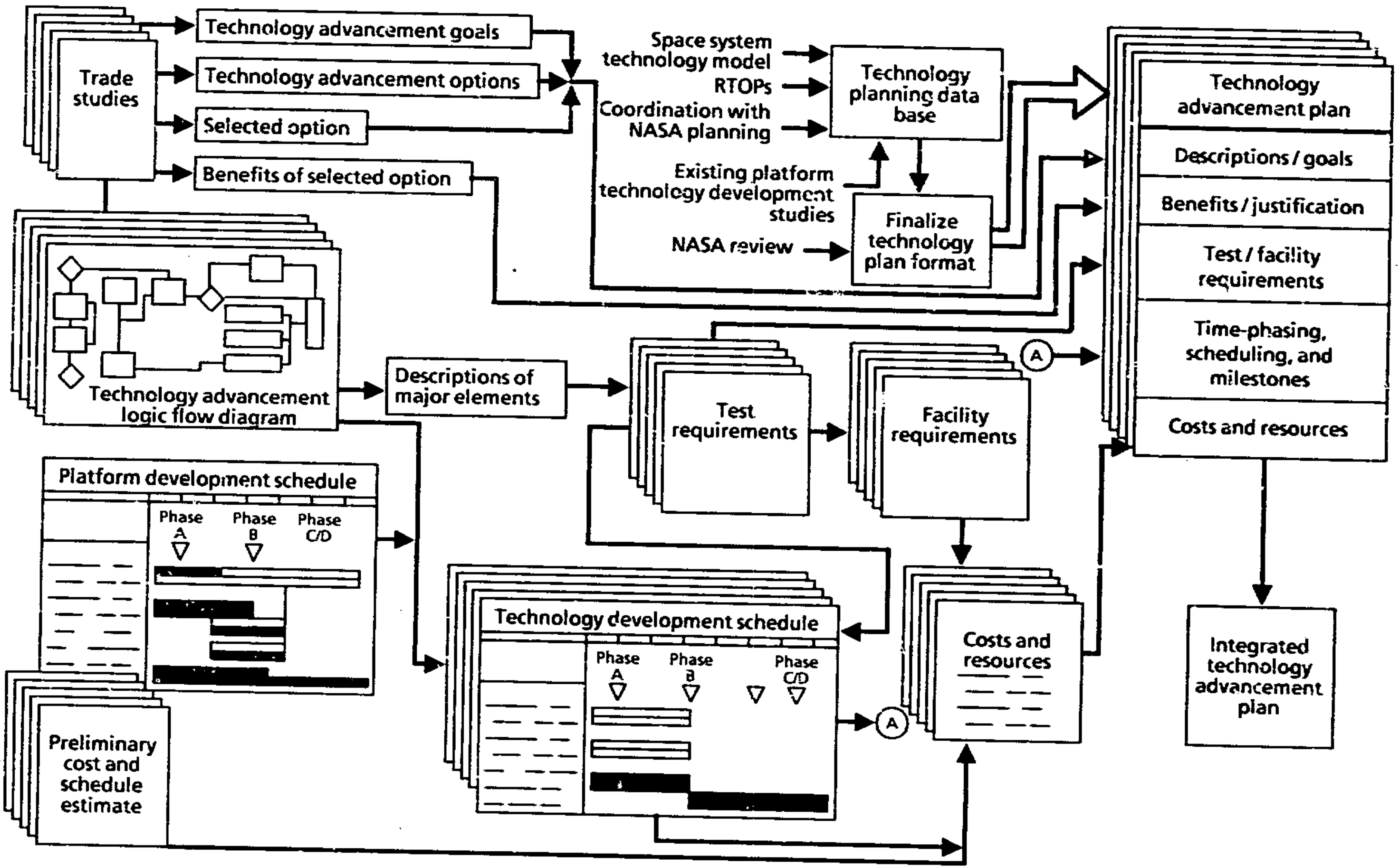

Figure 1.0-1. Task 3 Flow Diagram

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2.0 INTEGRATING CONTROLLER

2.1 INTRODUCTION

The integration of automated systems for providing Space Station utilities has been identified as a prime area for technology advancement. The issues addressed during this investigation were resolved in the initial tasks of this study as reported in Volume II of this final report. The benefits include cost savings as well as safety, efficiency, and enhancement to maintainability in Space Station design and operation. The controller for each subsystems (i.e., electrical power, life support, thermal control, etc.) will perform the actual control of the subsystem functions but the integrating controller will provide the priorities, constraints, and schedules which the subsystem will use. These priorities, constraints, and schedules can be updated by the integrating controller whenever overall balance of the space station operations, missions, and subsystem performance indicates the need.

The integrating controller will be developed in two phases, Phase I is intended for the IOC Space Station. It will consist of the development of subsystem models designed to evaluate state and mode conditions of seven prime subsystems and an overall Space Station needs model. These subsystem models will continuously assess the current operating conditions and synthesize the status information needed by the IC. The overall station model will be operating concurrently to define the needs of the Space Station as a whole. The actual functional conditions will be compared with the generated requirements and displayed to the astronauts and ground controllers. Initially, corrective action will be determined and subsystem adjustments made by humans with the IC acting in an advisory capacity.

Phase II will incorporate the overall integration of autonomous functional control. An expert system will be developed to perform the situation comparison task and determine corrective action necessary through the use of encoded knowledge derived from experts in the subsystem fields and the experience of the ground controllers and astronauts involved in Phase I.

In the trade studies, five technologies were identified as both critical to the integrating controller and lacking in maturity to support the needs of the Space Station. They are:

- Effective Space Station software simulation models,
- Real-time expert systems,
- Expert system/conventional microprocessor interfaces,

- Inference processors for spacecraft applications, and
- Knowledge acquisition and representation techniques.

Research in current and planned activities in other government agencies and industry is expected to provide some of the needed technology advancements. The Defense Advanced Research Projects Agency has established a Strategic Computing study (reference Strategic Computing, New Generation Technology: A Strategic Plan for Its Development and Application to Critical Problems in Defense, AD-A141982). In this study the development of basic artificial intelligence technology is planned, including real time expert systems. This is a large program in which 6-10 research centers across the country will be established with a staffing of approximately 100 professionals each. Funding was planned to be $50M for FY84, $95M for FY85, $150M for FY86, and unspecified amounts for the out years. The total amount for the first three years was planned to be nearly $300M. Schedules show the development of a real time capability by 3rd quarter FY90. An initial one third to one half real time capability is scheduled for completion in 4th quarter FY86. Since the expert system for the integrating controller was originally intended for an early to mid 90's application to an evolutionary form of the IOC Space Station, this program, when it is implemented, should provide some of the necessary technology development in this area within a time frame that will support the integrating controller developments as previously planned in this Space Station Systems Technology Study. Agreements to share the technology with NASA have already been made. Also, under the DARPA program, advanced knowledge acquisition, representation, and inference techniques are planned to be developed. Since developments in these two areas for military ground and air systems should be largely applicable to spacecraft systems as well, only minimal technology work by NASA appears to be justified. However, these activities are only planned at this time. A close monitoring of those programs as they proceed may be desirable to assure developments don't diverge from NASA's needs.

The following sections describe plans for the three remaining areas in the list above, effective Space Station software simulation models, expert system/conventional microprocessor interfaces, and inference processors for spacecraft applications. The plans are presented as stand alone programs. However, in the case of the software interface development, the inference processor is the heart of the expert system which is one side of the interface, and therefore must be available in order to design and build the software. In the case of the Space Station and subsystem simulation development, the models produced by the technology program will be much more useful if produced using hardware and software techniques resulting from the real-time expert system and the

inference processor programs. Initial model development using conventional techniques should be acceptable, though.

In summation, unless all five developments (two by DARPA and three by NASA) above are pursued, critical pieces of technology will be missing in the other programs that will severely decrease their usefulness. The plans have been presented in this manner to take maximum advantage of technologies developed with the resources of other government agencies, and in so doing, allow NASA to use its technology resources in other critical areas.

2.2 IC SYSTEM MODELLING

The following discussion provides a technology advancement plan that is designed to develop technologies requiring advancement that are critical to the development of Space Station subsystem state and mode models. The subsystem models comprise the Phase I concept for the IOC Space Station integrating controller. For a more complete description of the Phase II integrating controller technology development plan, see Volume III of the previous study, "Space Station Systems Technology Study" (D180-27935-3).

2.2.1 Description and Benefits

A flow diagram to describe the steps involved to perform integrating controller functions is shown in Figure 2.2-1. Information is collected by the integrating controller from the astronauts, subsystem controllers, and from ground controllers. A state and mode simulation will be run using these inputs and subsystem models to predict future subsystem states. These models, one for each subsystem, are independent, discrete time, discrete state models. However, the attitude control, electrical power, and thermal management subystems may incorporate some continuous state simulation elements as part of the models.

A separate state simulation will be run producing descriptions of the state of the Space Station and the needs for resources provided by the subsystems. Trend data and other historical data are updated to reflect the latest collected information. A comparison of the subsystem model outputs and space state needs will be made to detect subsystem anomalies and to determine when changes of subsystem operation are required. Discrepancies are judged to be either life or mission threatening or non-threatening, and conditions are categorized as emergency or anomalous. When an emergency condition exists, emergency commands will be generated and issued to the subsystem controllers. Subsystem change directives will be determined and issued for any anomalous condition which exists.

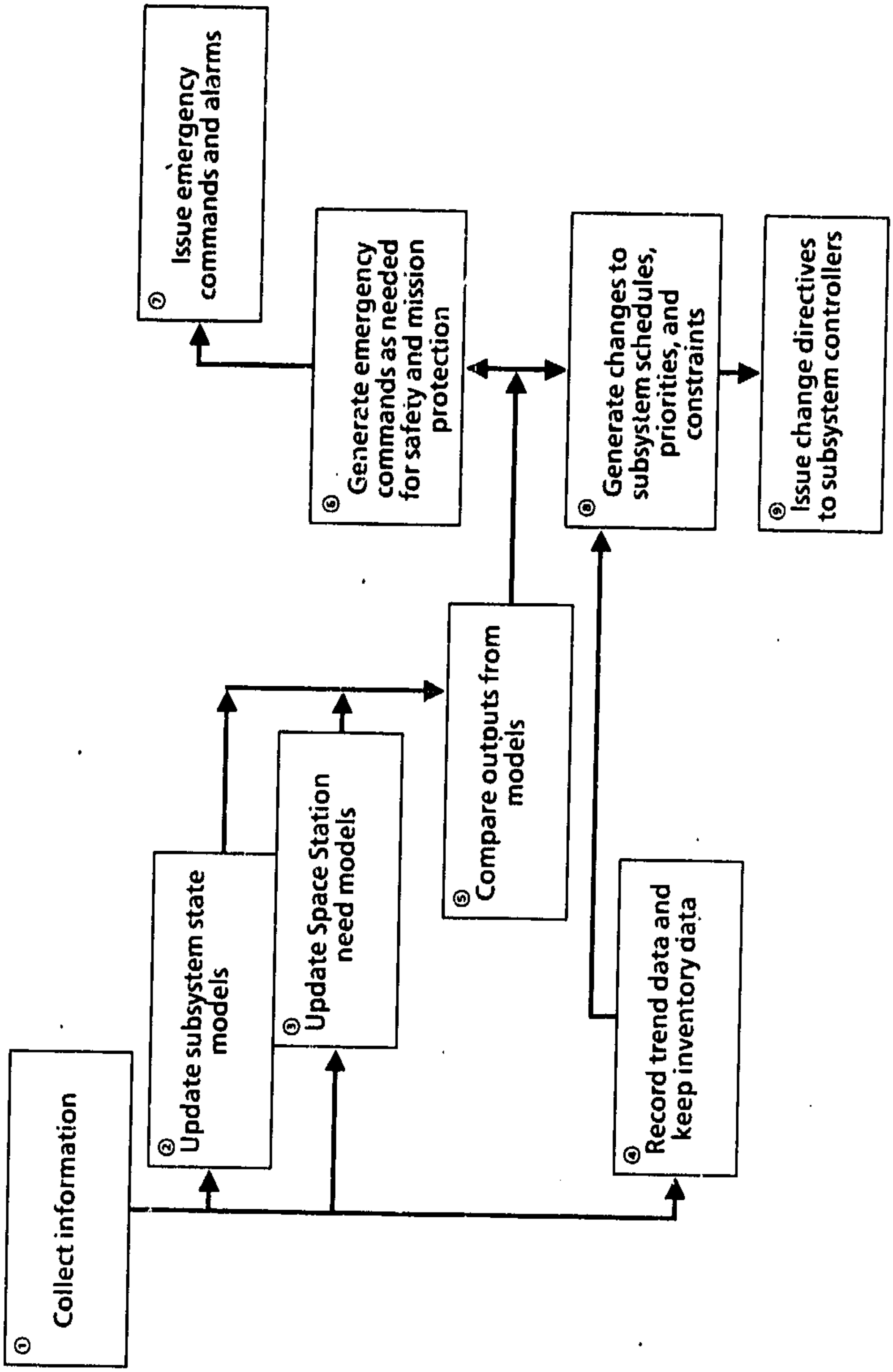


Figure 2.2-1. Flow Chart for Integration Controller Functions

Complex modeling software is a technology area necessary for the advancement of an integrating controller system. The development of effective subsytem models involves detail definition of the systems to be modeled and is a building block toward the overall development of the integrating controller.

A major purpose of the Space Station is to implement new designs, concepts, and methods that will reduce life-cycle costs, extend operational life and yield improved system performance. The development of an effective integrating controller which alerts each Space Station subsystem to potential failures and transmits reconfiguration information in the event of a failure so normal operations can continue supports this objective.

Other benefits of an integrating controller system for the Space Station are numerous and include the efficient use of resources and maintenance logistics, operations, and scheduling through the use of integrated management so that Space Station operations are not interrupted. Resupply and maintenance cost saving due to the integrating controller are estimated at <u>$25M over a 10-year mission</u>.

2.2.2 Technical Approach

An overall logic flow for the program is presented in Figure 2.2-2. The numbered blocks in the diagram relate directly to the steps outlined below. Each step describes the tasks and subtasks associated with this technology plan.

<u>STEP 1</u> Requirements Definition - This task involves several subtasks as outlined below:

a. Subsystem Definition - Specification of goals and objectives, and establishment of system boundary conditions.
b. Data Interface Requirements - Identification of necessary interface mechanisms between controllers, astronauts, ground personnel, and models.
c. Programming Language Selection - Selection of simulation language based upon evaluation of the characteristics of the model.
d. Real-time Software Capabilities - Deterministic study to assess the issues associated with translation of models into software suitable for real-time control.

<u>STEP 2</u> Simulation Development - During the course of this task, eight models will be developed in parallel. They include simulations of the attitude control, electrical power, thermal management, life support, data management and communications subsystems and also an overall Space Station mission and operations model which operates on subsystem data, plus data from ground controllers and astronauts. The results

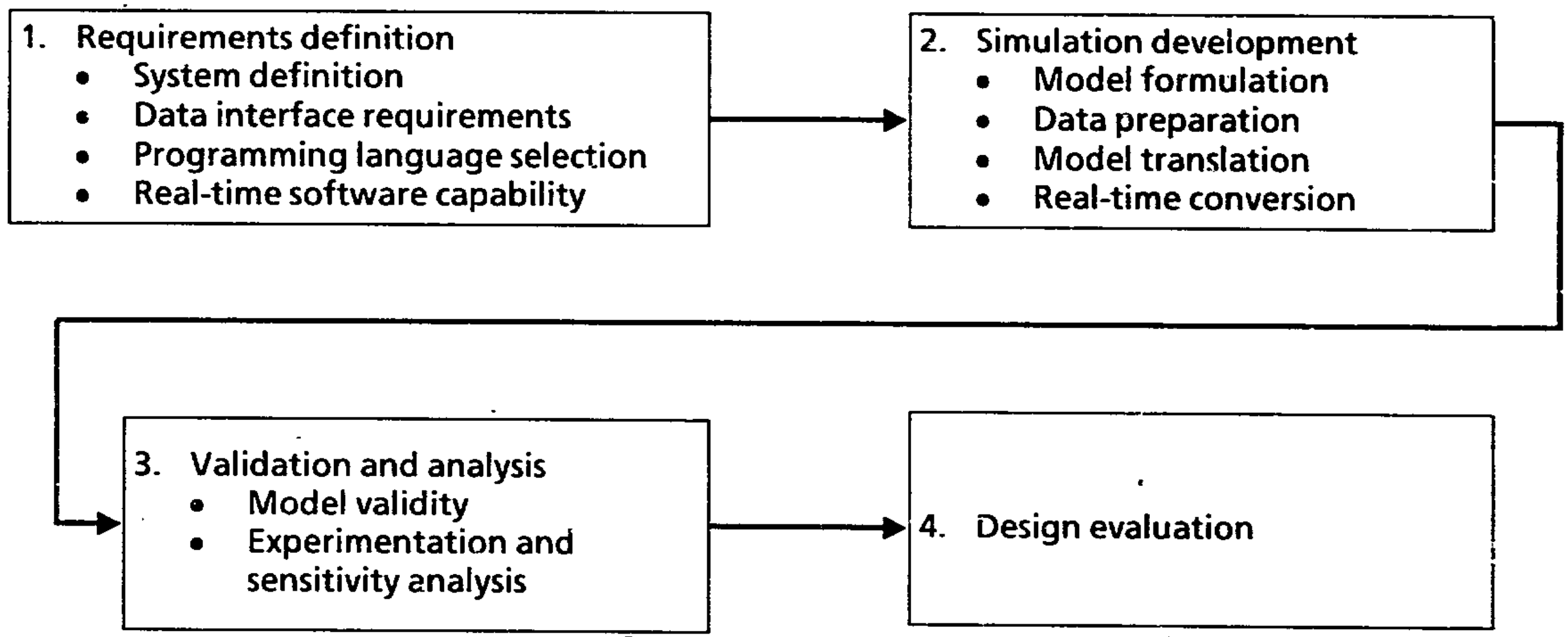


Figure 2.2-2. Logic Flow Diagram for Space Station Model Development

SS-1030/R1

of these models will be compared to those of the Space Station predictor models to determine where changes to subsystem operation are required. This task consists of the subtasks described below:

a. Model Formulation - Reduction of real system to a logical flow diagram.
b. Data Preparation - Identification of the data needed by the model and their reduction to an appropriate form.
c. Model Translation - Description of the model in a simulation language acceptable to the computer to be used.
d. Real-Time Conversion - Adaption of model into software suitable for real-time control.

STEP 3 Validation and Analysis - This task consists of the subtasks described below:

a. Modeling Validity - Evaluation of the model in order to develop an acceptable level of confidence that inferences drawn from the performance of the model are correct and applicable to the real world system.
b. Experimentation and Sensitivity Analysis - Execution of the simulation to generate the desired data and performance of analyses to determine the level of model sensitivity to input parameters.

STEP 4 Design Evaluation and Modification - Each model will be modified to incorporate any enhancements that may have been derived as a result of Step 3. Additionally design parameters such as memory requirements, run time, software size, etc. will be assessed to insure acceptabilty.

2.2.3 Facility Requirements and Candidate Facilities

Facilities requirements necessary to support the recommended development of space station subsystem simulation models include a scientific computer facility to develop software models using CAE techniques. Also interactive work stations should be employed to accommodate verification of functions. This facility would then be capable to provide necessary support during final design and operational phases of the Space Station.

Table 2.2-1 lists the NASA facilities that have capabilities pertinent to the various technology areas of space station subsystems. MSFC facilities specifically applicable for fulfilling the development requirements are indicated with an asterisk. Other center

TABLE 2.2-1

FACILITY CANDIDATES FOR INTEGRATING CONTROLLER SYSTEM MODELLING ADVANCEMENT PROGRAM

ID CODE	NASA CENTER AND FACILITY NAME
	Marshall Space Flight Center
4487-EC-11	Electronics Lab
4487-EC-12	*Control and Display Lab
4487-EC-14	Electronics Circuit Development Lab
4487-EC-16	*Microprocessor Applications Laboratory
4487-EC-20	Optical Test Lab
4487-EC-24	Optical Test and Fabrication Facility
4487-EC-35	Electrical Component Development Lab
4487-EC-45	Optical Shop for Fabrication of Optical Elements
4487-EC-48	*Microprocessor Laboratory
4659-AC-1	*Univac 1100/82
4659-AC-2	*Univac 1108
4708-AC-1	*IBM 360/75 General Purpose Computer System
4708-EF-8	*Digital Techniques Development Laboratory
4708-EF-11	*Electronic Development Lab's
4708-EF-13	*Data Systems Test and Development Laboratory
4708-EF-14	*Integrated Software Development Facility
4708-EF-20	*Experiment Data Systems Integration Lab
4708-ET-10	Payloads and Systems Test Laboratory
	Ames Research Center
N-233	Central Computer Facility
	Johnson Space Center
440	Communications Component Development Laboratory
440	Command and Modulation Laboratory
15	Laboratory, Spacecraft Data Systems
440	Electro-Optical Television Systems
	Langley Research Center
1268	Data Reduction Center

facilities have some of the same capabilities and could be used. Based on this review, no new facilities should be necessary to support the proposed development program.

2.2.4 Schedules

The major milestone schedules for parallel development of eight subsystem simulation models for advancement of the space station integrating controller technology and the predictor models are shown in Figure 2.2-3. This schedule would be based (initially) on an interactive control system with evolution to a more autonomous system for a growth space station in the mid- to late 1990's. The evolutionary system would be derived by integrating expert systems developments with the initial integrating controller based on these subsystems modeling tasks. (The expert system developments will not be available by the FY 87 phase C/D.) For a more complete description of the evolutionary integrating controller technology, see Volume II of this report and the results of two previous studies "Advanced Platform Systems Technology Study" (NAS8-34893) and "Space Station Systems Technology Study" (NAS8-34893, S/A No. 3).

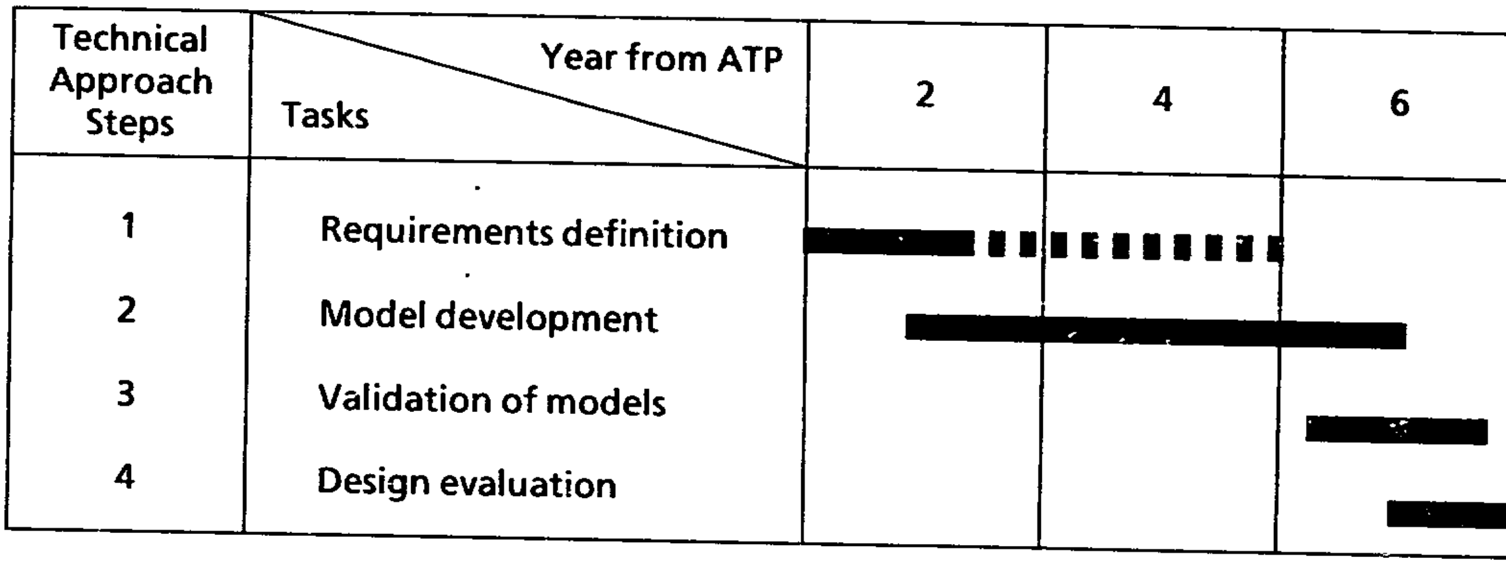
2.2.5 Resources

The time-phased resource requirements estimated for the Space Station subsystem model development effort are shown in Table 2.2-2. The cost of the Phase I program is approximately $2M. This figure includes the 16 man-years (@ $120,000/man-year) for development of the models plus an additional $60K worth of effort to select development languages and develop real-time capabilities. This brings the total to approximately $2M which was then allocated to the four tasks with the largest portion of $1.12M going to the second task.

The Phase II cost approximation of $2.12M as detailed in Volume III of the previous study, "Space Station Systems Technology" (NAS8-34893) which consists of the remainder of the developments necessary to accomplish Phase II and produce the autonomous IC has been revised from $2.12M to $3M as a result of a better definition of the effort required to produce the rules. The total cost for the IC technology development program is $7M ($2M + $2M + $3M).

2.3 EXPERT SYSTEM/CONVENTIONAL MICROPROCESSOR SOFTWARE INTERFACES

The expert system, as described in Volume II, will poll the subsystem controllers throughout the station for status information and send back mode control commands. In order to accomplish this, the necessary OP codes in the microprocessors of the subsystems must be identified along with the hardware specific characteristics such as pin assignments and timing. This plan describes a technology development in which



Dark lines indicate heavy emphasis.

Dotted lines indicate coordination emphasis.

Figure 2.2-3. Schedule for Space Station Subsystem Simulation Development Plan

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Table 2.2-2. Resources for Space Station Subsystem Simulation Development Plan

Technical Approach Steps	Tasks / Year from ATP	2	4	6	Total
1	Requirements definition	260	100		360
2	Model development	300	800	50	1150
3	Validation of models		220	150	370
4	Design evaluation			120	120
Total		560	1120	320	2000

1) Figures in $1000 (1984)
2) Estimates taken from midterm report, "Space Station Systems Technology Study"

006L-037

several major components of the subsystems and the expert system processor will be analyzed, and efficient software algorithms will be designed and developed to provide for communications between them. In addition, a laboratory brassboard of the system will be constructed and then used to validate the software. The plan assumes an existing inference processor will be supplied from outside the program for use in the brassboard.

2.3.1 Description and Benefits

The plan below describes a program that is concerned with system definition and software development and testing. This is an enabling technology for the integrating controller and is justified to obtain the $54M in benefits over the 10-year Space Station life that is made possible by the integrating controller. Since the interfaces software will be specific to the typical spacecraft hardware microprocessors and the inference processor, no program outside of NASA is likely to produce the same results as the technology program described herein.

2.3.2 Technical Approach

An overall logic flow for this program is shown in Figure 2.3-1. The numbered blocks relate directly to the steps outlined below. They describe tasks associated with this technology from initial architecture definition to validation and testing.

<u>STEPS 1 and 2</u>: Space Station Data Management and Integrating Controller Architecture Definition - In the first two steps, the structure (topology, protocol, etc.) of the respective systems will be defined in order to provide an understanding of the software/hardware that exists on both sides of the interface.

<u>STEP 3</u>: Establish Partitions Between IC and CDMS Functions - The criteria for establishing which functions should be performed by the distributed microprocessor controllers and which are better performed at the IC level will be defined. A conceptual design of the interface software will be produced.

<u>STEP 4</u>: Identify Functional Interfaces Between All Software and Distributed Microprocessor Instruction Set - The identification of microprocessor instruction set members that will be addressed by the interface software is the purpose of this task. The instructions identified will be those required to accomplish the functional partitioning identified in the previous subtask. Algorithms to perform the interface functions will be derived.

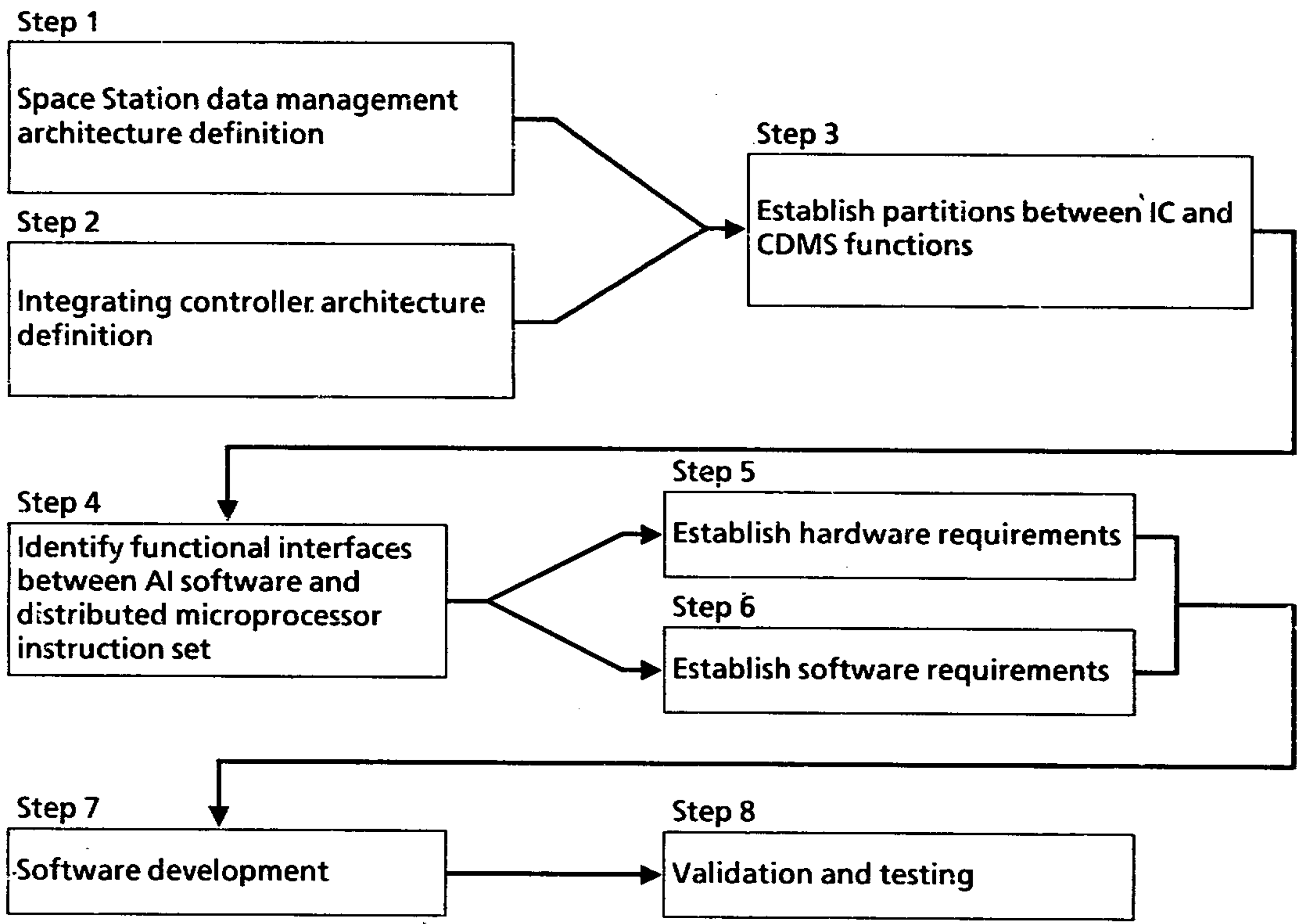

Figure 2.3-1. Logic Flow for IC Expert System/Conventional Microprocessor Software Interfaces

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STEP 5 and 6: Establish Hardware and Software Characteristics - A detailed description of the computer codes and equipment on which it will operate will be performed in preparation for the next task.

STEP 7: Software Development - The computer programs that will make up the interface software set will be written from the algorithms produced in Step 4 to the specifications produced in the previous task. Codes will be developed, debugged, and validated in this and the next task. In this task, the brassboard of the IC expert system and the representative conventional microprocessors will be constructed. Initial development of the software may proceed on conventional computer resources using software development tools. When the brassboard hardware is completed, development should shift to that system and be completed there.

STEP 8: Validation and Testing - In this step, the software is exercised to discover and correct any remaining bugs, evaluate and extend the capabilities of the software to operate over a range of conditions representative of worst case and nominal operations of the Space Station, and to install streamlining and fault tolerant features in the programs. Iterations between testing and software redesign (Steps 7 and 8) are intended.

2.3.3 Facility Requirements and Facility Candidates

Facility requirements to support the development of IC expert system/conventional microprocessor interfaces include a scientific computer facility to develop initial models using CAE techniques. Also interactive workstations should be employed to accommodate verification of functions in an efficient manner.

Additionally, an electronics laboratory/workshop in which the brassboard components can be constructed, assembled, and tested will be required. The use of any existing subsystem breadboards to evaluate these developments would be most beneficial.

Table 2.3-1 lists the NASA facilities that have capabilities pertinent to the various technology areas of space station subsystems. MSFC facilities specifically applicable for fulfilling the development requirements are indicated with an asterisk. Other center facilities have some of the same capabilities and could be used. Based on this review, no new facilities should be necessary to support the proposed development program.

2.3.4 Schedules

The major milestone schedules for this program are shown in Figure 2.3-2. The four year schedule shown has been derived to support development of a mid-1990's growth Space Station. Since the fully autonomous IC is not expected to be developed in time to

TABLE 2.3-1

FACILITY CANDIDATES FOR INTEGRATING CONTROLLER/MICROPROCESSOR INTERFACE ADVANCEMENT PROGRAM

ID CODE	NASA CENTER AND FACILITY NAME
	Marshall Space Flight Center
4487-EC-11	Electronics Lab
4487-EC-12	*Control and Display Lab
4487-EC-14	Electronics Circuit Development Lab
4487-EC-16	*Microprocessor Applications Laboratory
4487-EC-20	Optical Test Lab
4487-EC-24	Optical Test and Fabrication Facility
4487-EC-35	Electrical Component Development Lab
4487-EC-45	Optical Shop for Fabrication of Optical Elements
4487-EC-48	*Microprocessor Laboratory
4659-AC-1	*Univac 1100/82
4659-AC-2	*Univac 1108
4708-AC-1	*IBM 360/75 General Purpose Computer System
4708-EF-8	*Digital Techniques Development Laboratory
4708-EF-11	*Electronic Development Lab's
4708-EF-13	*Data Systems Test and Development Laboratory
4708-EF-14	*Integrated Software Development Facility
4708-EF-20	*Experiment Data Systems Integration Lab
4708-ET-10	Payloads and Systems Test Laboratory
	Ames Research Center
N-233	Central Computer Facility
	Johnson Space Center
440	Communications Component Development Laboratory
440	Command and Modulation Laboratory
15	Laboratory, Spacecraft Data Systems
440	Electro-Optical Television Systems
	Langley Research Center
1268	Data Reduction Center

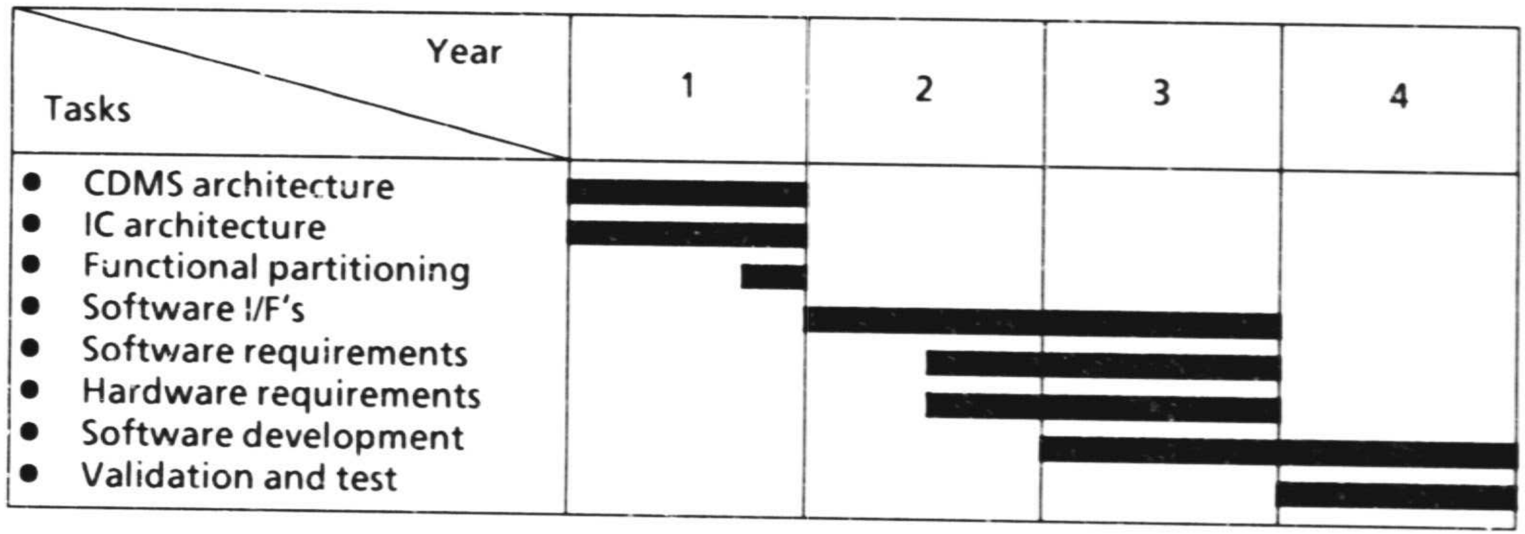

Figure 2.3-2 Schedule for IC Expert System/Conventional Microprocessor Software Interfaces

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support the IOC station, this effort supports the development of the autonomous IC during the initial operational phases of the station and would be put in place when the modifications for the autonomous controller are made. Considering a phase C/D start on the IOC station in the third quarter of FY87, the start date for this project could be as early as one year before IOC Space Station phase C/D, in which case the interface definitions of this task would drive certain aspects of the inference processor development in the next plan. Alternately, the start of this program could be delayed until the second year of the interference processor development program. In that case some aspects of the interface software design could be driven by the form of the inference processor defined in the other study. Some overlap of the phase C/D Space Station program will be necessary. The program can be considered as having two phases:

(1) Data Management Architecture Definition
(2) IC Architecture Definition
(3) Establish Criteria for Partitioning Functions into Two Groups Above
(4) Identify Functional Interfaces Between AI Software (2) and Distributed Microprocessors of (1)

ABOVE IS PRE-SS PHASE C/D WORK (4TH QUARTER FY87)

(5) Establish Hardware Requirements
(6) Establish Software Requirements
(7) Software Development
(8) Validation and Testing

ABOVE PICKS UP WITH START OF PHASE C/D WORK AND RUNS CONCURRENT WITH IT

2.3.5 Resources

The time-phases resource requirements estimated for this program are shown in Table 2.3-2. The total cost estimate for this plan is approximately $2M. This figure includes the 15 man-years (@ $120,000/man-year) for steps four through eight plus an additional $240K to characterize the system architectures and define the functional partitions. This brings the total to $2.04M with the largest portions, $480K each, going to the software development and testing tasks. Staffing and cost remains fairly constant after the first year at five people/year or $600K/year.

Cost estimates for the overall development of the autonomous IC technology consists of the $2M in this plan, the $2M in the previous plan for the system modeling, and an additional $3M to cover the inference processor development and other items. This brings the overall autonomous IC technology development cost to approximately

Step	Tasks / Year from ATP	1	2	3	4	Total
1	CDMS architecture	60				60
2	IC architecture	60				60
3	Functional partitioning	120				120
4	Software I/F's		300	60		360
5	Software requirements		150	90		240
6	Hardware requirements		150	90		240
7	Software development			360	120	480
8	Validation and test				480	480
Total		240	600	600	600	2040

Table 2.3-2. Resource Requirements for IC Expert System/Conventional Microprocessor Software Interfaces

SS-1035/R1

$7M ($2M + $2M + $3M). This figure is optimistic because it assumes that real time expert system and advanced knowledge acquisition techniques will be developed and will be applicable to NASA's needs, by DARPA in the "Strategic Computing Initiative" program.

2.4 COMPACT LIGHTWEIGHT INFERENCE PROCESSOR FOR SPACE APPLICATIONS

As described in Volume II, the decision making component of the IC is the expert system. The current state of the art in expert systems includes programming in languages such as LISP on conventional virtual memory or supermini computers. An example is the Space Station power system controller developed by Martin Marietta for MSFC. The expert system just for that subsystem controller taxed the resources of a VAX 11/780 computer. The IC expert system is expected to be several times the size (number of rules) of that expert system. Furthermore, the VAX computer is not designed to optimize volume, weight, and power requirements or hardened against cosmic ray single event upsets as spacecraft computer hardware must be. The need clearly exists for a large capacity, fast, computer for the Space Station IC.

2.4.1 Description and Benefits

The plan below describes a program that is designed to pursue the development of an inference processor (the heart of the computer) that will have significantly higher performance than existing processors through the use of the parallel and symbolic processing techniques. Also, this processor will be designed from the start for use in a spacecraft. Texas Instruments is pursuing the development of a similar processor and is expected to produce initial results in six years. However, the requirements driving that design and the date of completion do not fully meet the needs of the Space Station program. In order to provide the necessary technology for the late 1990's Space Station, advanced development in this area is needed. This is an enabling technology for the integrating controller. It is justified because it will obtain the $54M in benefits over the 10-year Space Station life that is made possible by the integrating controller. No program outside of NASA is likely to produce the same results as the technology program described herein.

2.4.2 Technical Approach

An overall logic flow for this program is shown in Figure 2.4-1. The numbered blocks relate directly to the steps outlined below. They describe tasks associated with developing a new type of microprocessor that will provide the computational speed

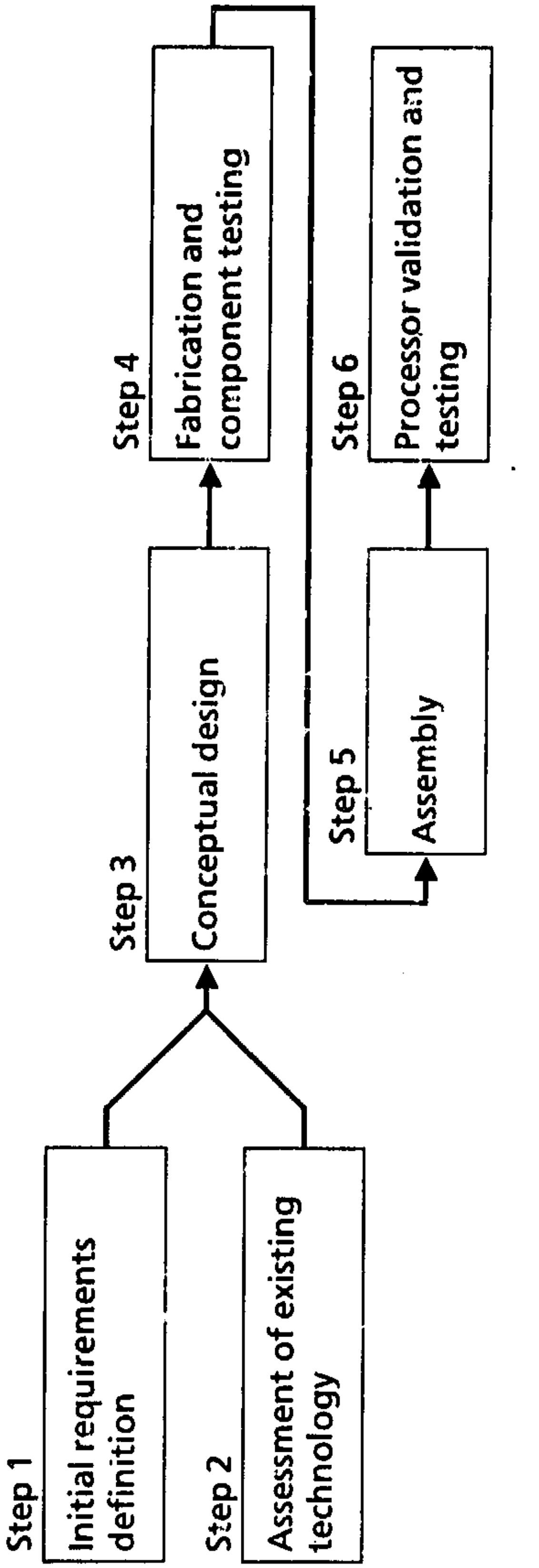

Figure 2.4-1. Logic Flow for Development of Compact Lightweight Inference Processor for Space Applications

SS-1036/R1

necessary to perform real time operations with the integrating controller's expert system.

STEP 1 and 2: Initial Requirements Definition and Assessment of Existing Technology - Available expert system technology will be characterized and compared with the needs of a Space Station.

STEP 3: Conceptual Design - Conceptual design of the processor will be performed.

STEP 4: Fabrication and Component Testing - Prototype microcircuit components necessary to perform symbolic and numeric processing in parallel will be fabricated.

STEPS 5 and 6: Assembly and Processor Validation Testing - The components will be assembled into a brassboard for subsequent validation.

2.4.3 Facility Requirements and Facility Candidates

Facility requirements to support the development of a compact lightweight inference processor for space applications include a scientific computer facility to perform conceptual design studies. Also interactive workstations should be employed to enable fast and efficient development.

Additionally, an electronics laboratory/workshop in which the brassboard components can be constructed, assembled, and tested will be required. The use of any existing subsystem breadboards in testing of the prototype processor would be most beneficial.

Table 2.4-1 lists the NASA facilities that have capabilities pertinent to the development and building of microprocessors. MSFC facilities specifically applicable for fulfilling the development requirements are indicated with an asterisk. Other center facilities have some of the same capabilities and could be used. Based on this review, no new facilities should be necessary to support the proposed development program.

2.4.4 Schedules

The major milestone schedules for this program are shown in Figure 2.4-2. The six year schedule shown has been derived to support development of a late 1990's growth Space Station. Since the fully autonomous IC is not expected to be developed in time to support the IOC station, this effort suports the development of the autonomous IC during the initial operational phases of the station and would be put in place when the modifications for the autonomous controller are made. Considering a phase C/D start on the growth station at three to five years before IOC, the start date for this project must

TABLE 2.4-1
FACILITY CANDIDATES FOR THE INFERENCE PROCESSOR ADVANCEMENT PROGRAM

ID CODE	NASA CENTER AND FACILITY NAME
	<u>Marshall Space Flight Center</u>
4487-EC-11	Electronics Lab
4487-EC-12	*Control and Display Lab
4487-EC-14	Electronics Circuit Development Lab
4487-EC-16	*Microprocessor Applications Laboratory
4487-EC-20	Optical Test Lab
4487-EC-24	Optical Test and Fabrication Facility
4487-EC-35	Electrical Component Development Lab
4487-EC-45	Optical Shop for Fabrication of Optical Elements
4487-EC-48	*Microprocessor Laboratory
4659-AC-1	*Univac 1100/82
4659-AC-2	*Univac 1108
4708-AC-1	*IBM 360/75 General Purpose Computer System
4708-EF-8	*Digital Techniques Development Laboratory
4708-EF-11	*Electronic Development Lab's
4708-EF-13	*Data Systems Test and Development Laboratory
4708-EF-14	*Integrated Software Development Facility
4708-EF-20	*Experiment Data Systems Integration Lab
4708-ET-10	Payloads and Systems Test Laboratory
	<u>Ames Research Center</u>
N-233	Central Computer Facility
	<u>Johnson Space Center</u>
440	Communications Component Development Laboratory
440	Command and Modulation Laboratory
15	Laboratory, Spacecraft Data Systems
440	Electro-Optical Television Systems
	<u>Langley Research Center</u>
1268	Data Reduction Center

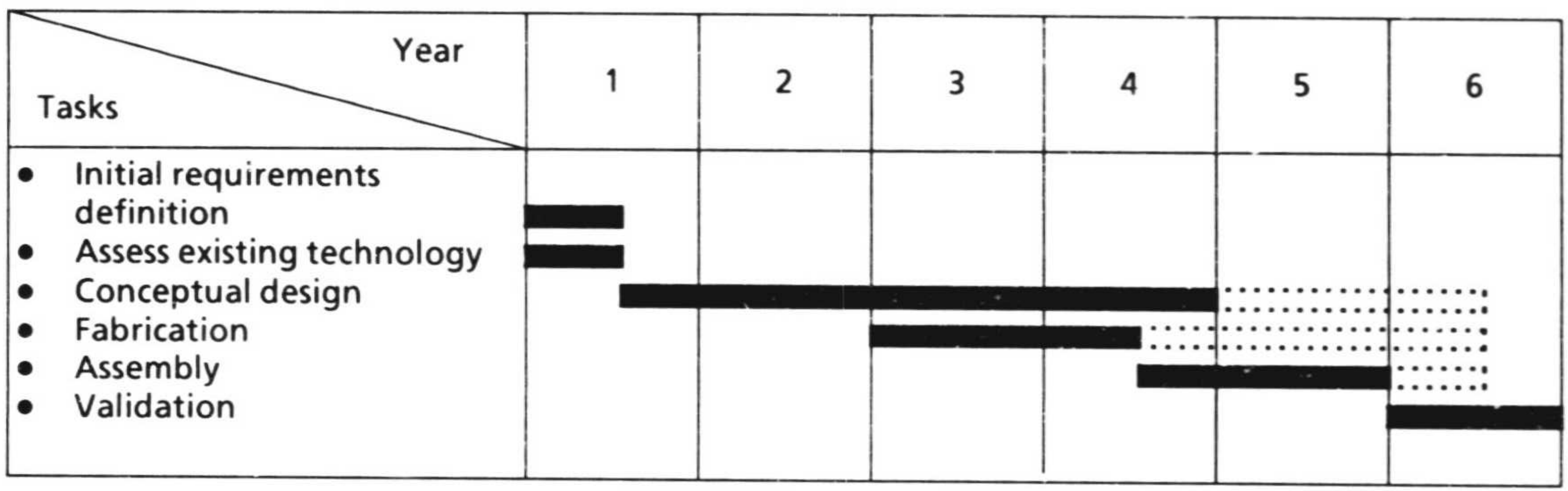

Figure 2.4-2. Schedule for Development of Compact Lightweight Inference Processor for Space Applications

SS-1037/R1

precede IOC by 9-11 years. Therefore, this development program requires a start fairly soon or overlap of phase C/D of the growth Space Station program will be necessary.

2.4.5 Resources

The time-phased resource requirements estimated for this program are shown in Table 2.4-2. The total cost estimate for this plan is approximately $3.7M. This figure includes 30 man-years (@ $120,000/man-year) plus an additional $100K for equipment and materials. This brings the total to $3.7M with largest portion, $1.2M, going to the conceptual design task. Staffing and cost remains fairly constant at five people/year or $600K/year.

Cost estimates for the overall development of the autonomous IC technology consists of the $3.7M in this plan, the $2M for the system modeling, and $2M for the interface software development. This brings the overall autonomous IC technology development cost to approximately $7.7M ($2M + $2M + $3.7M). This figure is optimistic as it is based on the assumptions that real time expert system and advanced knowledge acquisition techniques will be developed and will be applicable to NASA's needs, by DARPA in the "Strategic Computing Initiative" program.

Step \ Year	1	2	3	4	5	6	Total
Initial requirements definition	150						150
Assess existing technology	150						150
Conceptual design	300	600	200	100			1200
Fabrication			440	440			880
Assembly				100	620		720
Validation						600	600
Total	600	600	640	640	620	600	3700

Table 2.4-2. Resource Requirements for Development of Compact Lightweight Inference Processor for Space Applications

SS-1038/R1

3.0 CONTROLS AND DISPLAYS

3.1 INTRODUCTION

The next three items covered in section 3.2, 3.3, and 3.4 relate to the area of controls and displays technology. The first, is the development of a head-up display device with a very wide field-of-view (60°) to accommodate an operator at an OMV teleoperator control station. While there is a significant amount of effort being expended in the development of new display techniques, no effort to widen the field-of-view to this extent has been identified in industry or within government agencies. The possible reason is a lack of specific requirement for a very wide FOV version. Typically aerospace needs are satisfied by the wide field of view configuration (30°) such as the one that has already flown in the Space Shuttle.

The next two plans cover the emerging technologies in liquid crystal displays. The first is the development of large flat panel displays (8 inch diagonal) using LCD technology to replace CRT screens. The second is the application of flat panel technology to a switch. A single switch would be used for many purposes by programming its function and the label on the switch.

The requirements for these technologies and their benefits in an OMV teleoperations workstation were identified in the trade studies presented in volume II of this report. The programs described in the following plans for controls and displays technology advancements will provide the basic technology necessary to capture those benefits in the Space Station.

3.2 VERY WIDE FIELD-OF-VIEW HEAD-UP DISPLAY

This technology plan concerns the development of a new very wide field-of-view head-up display (WFOV/HUD) device which may be used in the proximity control of vehicles. This item has been identified as beneficial in controlling an orbital transfer vehicle (OTV) or the orbital maneuvering vehicle (OMV) in the Space Station operational scenario. it is superior to conventional technology because it allows operators to simultaneously view the outside scene and computer-generated instrumentation symbology. By doing so it reduces fatigue and the disorienting effects of shifting concentration between two different areas in the workstation.

3.2.1 Descriptions and Benefits

The head-up display (HUD) is an instrument in which computer generated symbology is projected onto a clear combining surface mounted in the operator's field-of-view (FOV). By projecting images into the FOV, the operator is able to simultaneously view

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the outside scene as well as the symbology. The technology for HUD development can be divided into two categories based on the required FOV:

a. Reflective/refractive optics for small FOV (15°-20° FOV horizontal).
b. Diffraction optics for larger FOV (20°-30° or greater FOV horizontal).

Typical HUDs for the reflective/refractive optics and the diffraction optics are shown in Figures 3.2-1 and 3.2-2.

For the reflective/refractive optics HUD, displays from a cathode ray tube (CRT) are directed onto the combining surface by the relay lens, folding mirror, and collimating lens. The collimating lens allows the displays to appear focused at infinity instead of the combining surface, thereby allowing the operator to view the outside scene and display simultaneously without having to refocus his eyes. The significant disadvantage to this type of system is that the available instantaneous FOV is restricted by the collimating lens as shown in Figure 3.2-1. Therefore, techniques must be integrated into the design or new methods for HUD image formation developed for increasing the available instantaneous FOV.

Diffraction optics have been used in HUD development to increase the FOV. By comparing Figure 3.2-1 and 3.2-2, it can be seen that the collimating lens is eliminated as a component in the HUD device. (For diffraction optics, the collimating lens is part of the combining surface.) As a result, the available instantaneous FOV is increased. Controlled optical effects can be achieved by using the property of diffraction, in which fringe effects are produced by the interaction of light with edges or slits. Light from an object containing image information such as a CRT is redirected by a diffraction element in which the optical property information such as direction and lens power is stored. The pioneer work in diffraction optics HUDS was done primarily by the Hughes Aircraft Company and the Environmental Research Institute of Michigan (ERIM). ERIM has limited their work to the fabrication of combiners and the development of computer programs for ray tracing. Hughes Aircraft has built several development models using diffraction optics HUD and has flight tested the device for the Swedish Air Force and for the Precision Attack Enhancement program developed by Martin Marietta Corporation. Marconi Avionics, Ltd. has been manufacturing diffractive optics since 1978. They were awarded a contract by the United States Air Force in 1980 to develop a new HUD incorporating diffraction optics for the F-16 and A-10 aircraft. THis system has a total FOV of 30° horizontally and 20° vertically and an instantaneous FOV of 30° horizontally and 18° vertically. The efficiency of transmission of the display to the pilot will be about 40 to 45% compared to 20% for the conventional HUD.

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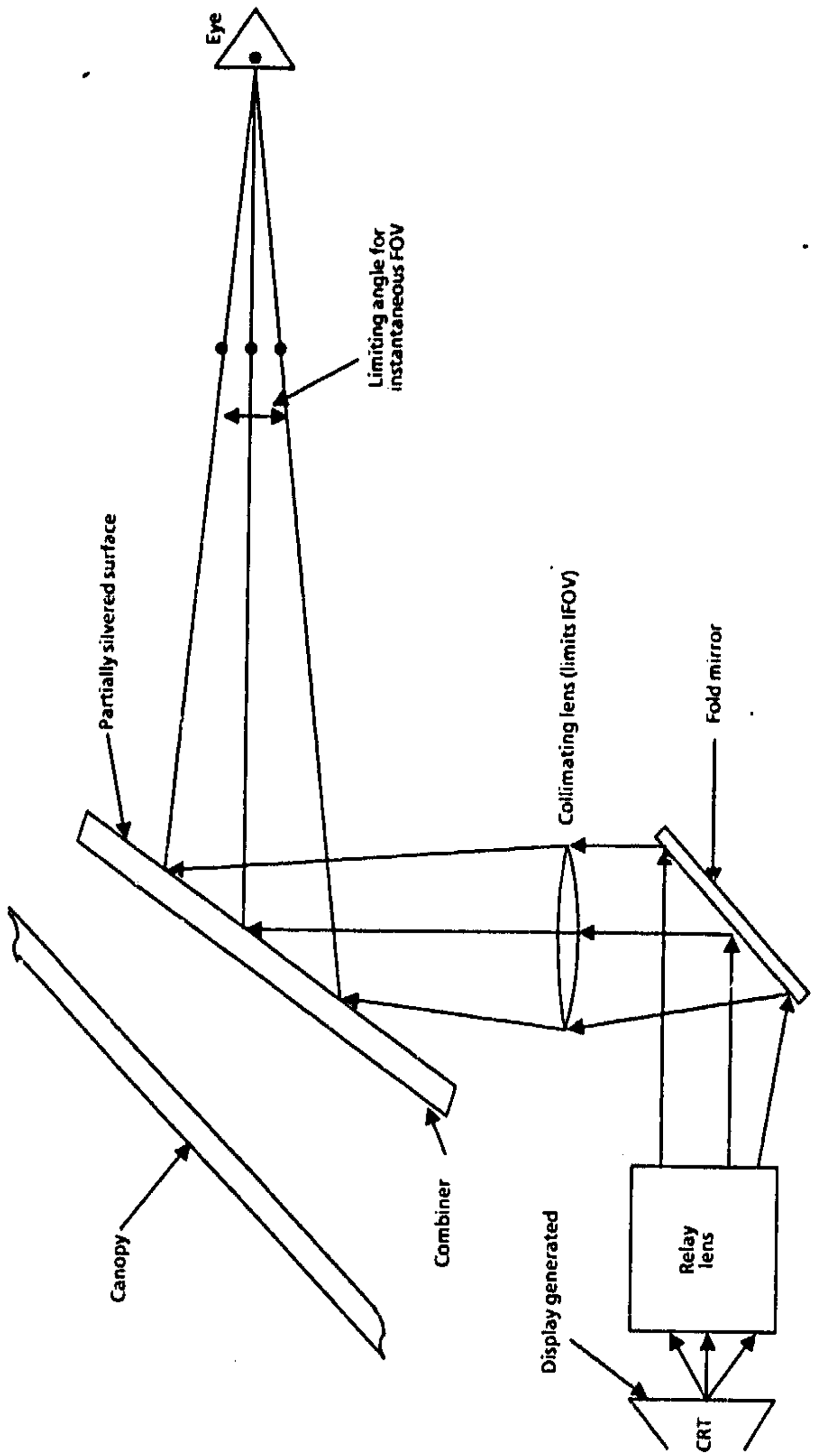

Figure 3.2-1. Conventional HUD Layout

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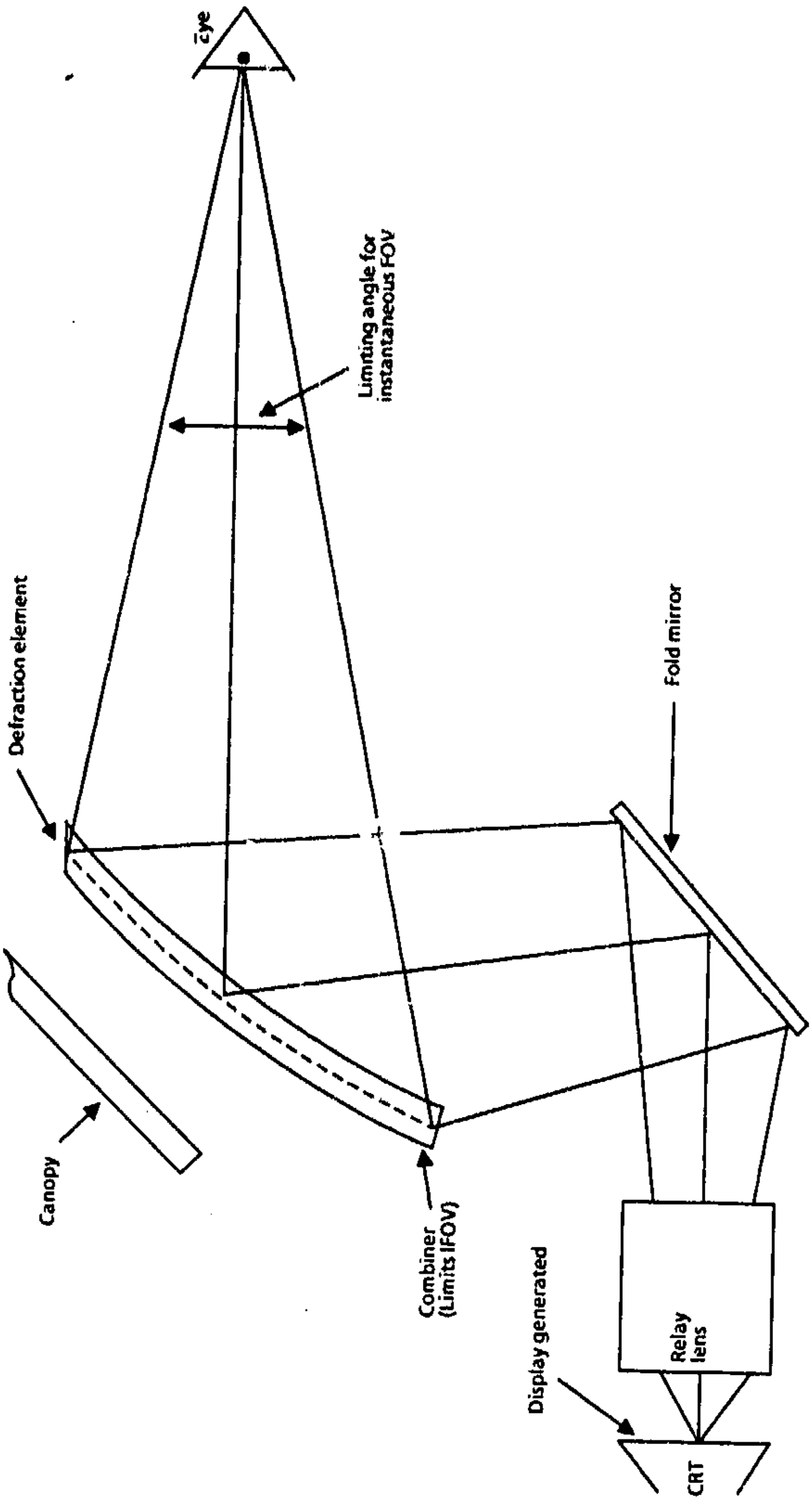

Figure 3.2-2. Defraction Optics HUD Layout

Because HUDs present all the information required during maneuvers in the immediate FOV of the operator, the integration of HUDs into the Space Station offers significant benefits in the areas of Space Station - OMV maneuvers and other proximity operations. By presenting all necessary information in the operator's FOV, attention-diversion problems and the continued eye reaccommodation by the operator is lessened. As a secondary benefit, the operator's workload and associated fatigue is decreased. Allowing the operator to view the displayed information as the proximity operations are controlled enables rapid evaluation of the progress and decreased response time during critical events.

In the trade studies performed by BAC to characterize a multifunction workstation for the Space Station, the WFOV/HUD was identified as one of the technologies that could lead to a reduction in manpower required to perform OMV, OTV, and spacecraft servicing, flight operations, and functions. In a ranking of benefit over existing techniques of the control and displays technologies, the WFOV/HUD was determined to have relatively high benefits, but at relatively high cost when compared to the other items. See volume II for a more complete discussion of the technology items and comparison of benefits and cost.

3.2.2 Technical Approach

An overall logic flow for this program is shown in Figure 3.2-3. The numbered blocks in the diagram relate directly to the steps outlined below. They describe tasks associated with this technology from initial requirements definition, through prototype development, to laboratory evaluation. This program features an overall workstation layout effort combined with a direct effort in the development of WFOV/HUD technology.

STEP 1: Initial Requirements Definition. The initial task of this study, this step will provide the detailed objectives and approach to WFOV/HUD and workstation development. Operational, functional, and ergonomic requirements on the workstation and an initial test spec for the lab evaluation phase will be produced during this effort.

SUBTASK 1.1: Functional Requirements Definition. Concepts for the role of the workstation and operator in the guidance, navigation and control of the teleoperated vehicles and mechanisms will be defined, appropriate methods for performing the functions of the workstation identified, and design requirements quantified to support the layout task.

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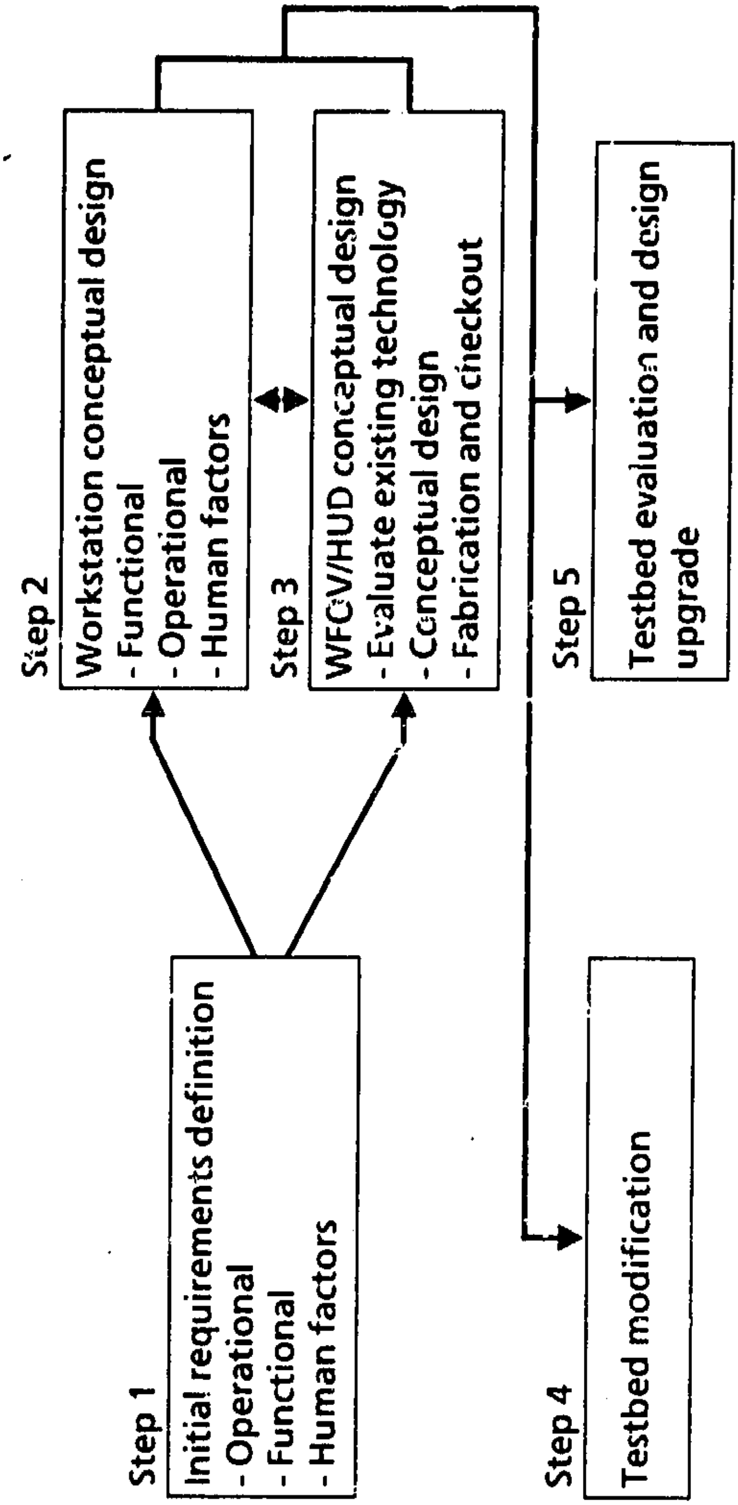

Figure 3.2-3. Logic Flow Diagram for WFOV/HUD Development

<u>SUBTASK 1.2</u>: Operational Requirements Definition. The command and data management, communications, and facility related requirements will be conceptually defined in the subtask. Software timing, accuracy, and interface requirements will be quantified.

<u>SUBTASK 1.3</u>: Economic or Human Factors Requirements Definition. The design aspects relating to support of the operator from a human factors standpoint will be studied to identify design requirements to alleviate fatigue and improve operator performance.

<u>STEP 2</u>: Workstation Conceptual Design. The subtasks below relate directly to the development of workstation concept developed around and supportive to the WFOV/HUD work in task 2. A conceptual layout will be developed from the requirements established in the previous subtasks. The layout will be documented to a level sufficient to support making the modifications to the laboratory configuration in MSFC's Robotics crew station facility. This effort will support evaluation of the WFOV/HUD to be developed in the next task.

<u>STEP 3</u>: WFOV/HUD Conceptual Design. The subtasks discussed below all relate specifically to the development of a prototype model for subsequent laboratory evaluations.

<u>SUBTASK 3.1</u>: Evaluation of Existing Technology. The recent developments in teleoperator control technology discussed in section 3.2.1 above will be evaluated for applicability to extended field-of-view devices. Trade studies to identify the design extensions or modifications necessary to meet the needs of the teleoperator workstation will be performed. Both diffraction and refraction/reflective techniques will be considered.

<u>SUBTASK 3.2</u>: Conceptual Design. A design task for the prototype model will be executed to produce specifications and drawings with a level of detail sufficient for fabrication of the device in the next subtask. Trade studies will be performed to determine a set of the best selections from design options (e.g., reflective, refractive, or diffractive, two dimensional or holographic imaging) for evaluation. Analytical simulation of visibility, transmission, and operator constraints will be performed to support the selection process.

SUBTASK 3.3: Fabrication and Checkout. In an appropriate shop facility a working models of the WFOV/HUD will be developed and their functions and operations checked out prior to delivery to the test lab.

STEP 4: Testbed Modification. Looking ahead to the workstation evaluation of the WFOV/HUD model prototypes, preparations will begin early by identifying the necessary modifications to the existing crew station testbed to support the design requirements established in the workstation and WFOV/HUD subtasks above (2.4 and 3.2 respectively). The necessary support equipment and fixtures will be fabricated and installed before delivery of the prototype test models. Some mods may have to be delayed to avoid interference with other tests being performed in the lab, but equipment and supplies can be stored nearby.

STEP 5: Testbed Evaluation and Design Upgrade. Finally, the prototypes will be delivered to the lab and installed with the workstation modifications. The functions of each HUD/workstation configuration will be verified per requirements established in Task 1 and the evaluation testing will proceed. Tests should include evaluations with a sufficiently large sample size of subjects in all the necessary proximity and remote operational scenarios required of the OMV including satellite servicing from the shuttle and Space Station, Space Station maintenance and servicing operations, and deployment/retrieval operations. Additional tests for control of the OTV and manipulators may also be performed for each configuration and operator subject. Following completion of the test program, the results will be evaluated to identify the best candidate prototype and suggest design upgrades for the actual WFOV/HUD and workstation.

3.2.3 Facility Requirements and Facility Candidates

Facility requirements to support the development of a wide FOV HUD are extensive. They include clean rooms, dark rooms, display panel simulation laboratories, precise optical benches, vibration stabilized laboratory, optical facilities for the production of precision optical devices, and computer facilities.

Table 3.2-1 lists candidate NASA facilities which have capabilities which will support this development program.

3.2.4 Schedule

The major milestones for the development of the WFOV/HUD are shown in Figure 3.2-4. The estimated timeframes for each major step is shown. This schedule could support a 1992 IOC date for the Space Station by completing technology in time to

TABLE 3.2-1

FACILITY CANDIDATES FOR WIDE FIELD-OF-VIEW HEAD-UP DISPLAY

ID CODE	NASA CENTER AND FACILITY NAME
	MARSHALL SPACE FLIGHT CENTER
4487	Active Optics and Computer Aided Design Laboratory
4708	Checkout Control Complex
4708	Checkout System Electrical Support Equipment
4708	Class 100,000 and Class 10,000 Clean Room
4610, 4663, 4491	Computer-Operated Simulation Facility
4487	Data Systems Test and Development Laboratory
4708	Electrical/Electronics Parts and Components Test Area
4728	Electronic Equipment Development Laboratory
4487	Large-Scale Integrated Circuit Development Laboratory
4487	Optical/Digital Image Processing Facility
4487	Optical Fabrication Shop
4487	Optical Test and Fabrication Facilities
4487	Remote Manipulator Systems R&D Laboratory
4708	Mission Avionics and Control Simulation Facility
4487	Simulation Laboratory, Control System
4487	Electronics Guidance and Control Development Lab
4481	Vibration Isolation Platform Facility
	JOHNSON SPACE CENTER
14	Electro-Optical and Laser Laboratory
16	Simulation Laboratory
9A	Mockup and Integration Laboratory
15	Physical Optics Laboratory
	GODDARD SPACE FLIGHT CENTER
5	Holographic Diffraction Grating Laboratory

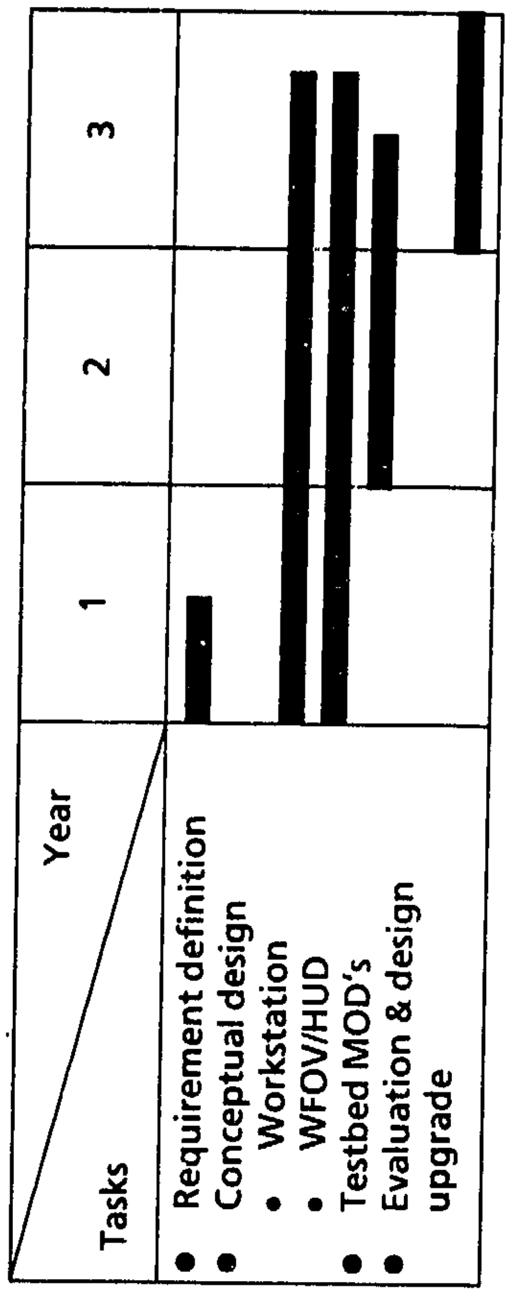

Figure 3.2-4. Schedule for Development of WFOV/HUD

support the phase C/D start in the first quarter of 1987, provided ATP occurs on the date shown. It is anticipated that should the need arise, this program could be compressed into a 12 month period at the minimum by limiting the number of prototypes tested and the number of workstation configurations, operator subjects, and tasks in the test.

3.2.5 Resources

The time phased resource requirements estimated for the WFOV/HUD are shown in Table 3.2-2. The cost of the program through the testbed analysis is approximately $1.782M of that total, $1.68M is estimated for labor (14 man-years x $120,000/man-years) plus $102K for materials and supplies. Final design definition and flight qualification for the Space Station is considered part of the Space Station program and is not addressed in this technology advancement program.

3.3 HIGH PERFORMANCE COLOR FLAT PANEL LCD DISPLAY

Currently, Cathode Ray Tubes are used widely for large screen workstation displays. In recent years LCD displays have been appearing in many applications where CRT's have been traditionally used (television screens, computer monitors, etc.). However, the largest version of the screen is approximately 9 inches diagonally. Space Station workstations have a need for larger displays due to the large amount of data requiring simultaneous display. A survey of the leading manufacturers of LCD displays was made to determine if a larger screen was in development. None of the companies contacted indicated any interest or intention in developing a larger device, primarily because the 9 inch screen satisfies their requirements and significant technical problems must be overcome to enlarge the screen further. The most significant technical hurdles include: decreasing element size to allow high resolution (80-100 lines per inch) graphics, decreasing the rise/fall time until it is comparable to a CRT (.1 second) to alleviate ghosting problems, increasing luminescence so that it functions well in a normal 35-50 foot-candle environment, increasing the angle at which it can be viewed from the current 20° to around 45°, and solving color saturation problems.

3.3.1 Descriptions and Benefits

LCD displays have several advantages over CRT's that are particularly important in spacecraft applications. Among these are a significant reduction in size (depth) and power requirements. Conversely LCD's have very few disadvantages compared to CRT's. Color capabilities and service life are at least comparable. The technical approach described below defines a program to solve the current limitations of LCD displays listed

Step	Tasks \ Year from ATP	1	2	3	Total
1	Requirements definition	120			120
2	Conceptual design				
	- Workstation	90	60		150
	- WFOV/HUD	270	280		450
3	Testbed modification		230	290	580
4	Test and evaluation			482	482
Total		480	530	772	1782

Table 3.2-2. Resources for WFOV/HUD

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in the previous section and to produce a prototype high performance color flat panel display.

3.3.2 Technical Approach

An overall logic flow for this program is shown in Figure 3.3-1. The numbered blocks in the diagram relate directly to the steps outlined below. They describe tasks associated with this technology from initial requirements definition, through prototype development, to laboratory evaluation. This program features an overall workstation layout effort combined with a direct effort in the development of large LCD display technology.

STEP 1: Initial Requirements Definition. Functional, operational, and ergonomic requirements for the display will be established.

STEP 2: Conceptual Design. Investigations will focus on enhancement of current techniques to provide high resolution graphics (80-100 lines per inch), fast rise and fall time (.1 seconds), sufficient luminance (35-50 foot-candle environment), and an increase in color saturation.

STEP 3: Brassboard Design and Fabrication. Includes design and fabrication of a brassboard model.

STEP 4: Testing. Testing of the display model will be performed in a workstation testbed. Finally, the flat panel display/workstation will be used to evaluate the design using a number of test subjects performing a variety of control and display tasks, with several different workstation layouts.

3.3.3 Facility Requirements and Facility Candidates

Facility requirements to support the recommended developments are as follows: (1) laboratory/shop facilities where a display prototype and testbed components can be fabricated, assembled, and checked out, and (2) Space Station multifunction control and display testbed.

Table 3.3-1 lists the NASA facilities which have capabilities pertinent to the various areas of control and displays development. Based on this review, no new facilities should be necessary to support these development programs.

TABLE 3.3-1

FACILITY CANDIDATES FOR LCD FLAT PANEL DISPLAY ADVANCEMENT PROGRAM

ID CODE	NASA CENTER AND FACILITY NAME
	MARSHALL SPACE FLIGHT CENTER
4487	Active Optics and Computer Aided Design Laboratory
4708	Checkout Control Complex
4708	Checkout System Electrical Support Equipment
4708	Class 100,000 and Class 10,000 Clean Room
4610, 4663, 4491	Computer-Operated Simulation Facility
4487	Data Systems Test and Development Laboratory
4708	Electrical/Electronics Parts and Components Test Area
4728	Electronic Equipment Development Laboratory
4487	Large-Scale Integrated Circuit Development Laboratory
4487	Optical/Digital Image Processing Facility
4487	Optical Fabrication Shop
4487	Optical Test and Fabrication Facilities
4487	Remote Manipulator Systems R&D Laboratory
4708	Mission Avionics and Control Simulation Facility
4487	Simulation Laboratory, Control System
4487	Electronics Guidance and Control Development Lab
4481	Vibration Isolation Platform Facility
	JOHNSON SPACE CENTER
14	Electro-Optical and Laser Laboratory
16	Simulation Laboratory
9A	Mockup and Integration Laboratory
15	Physical Optics Laboratory
	GODDARD SPACE FLIGHT CENTER
5	Holographic Diffraction Grating Laboratory

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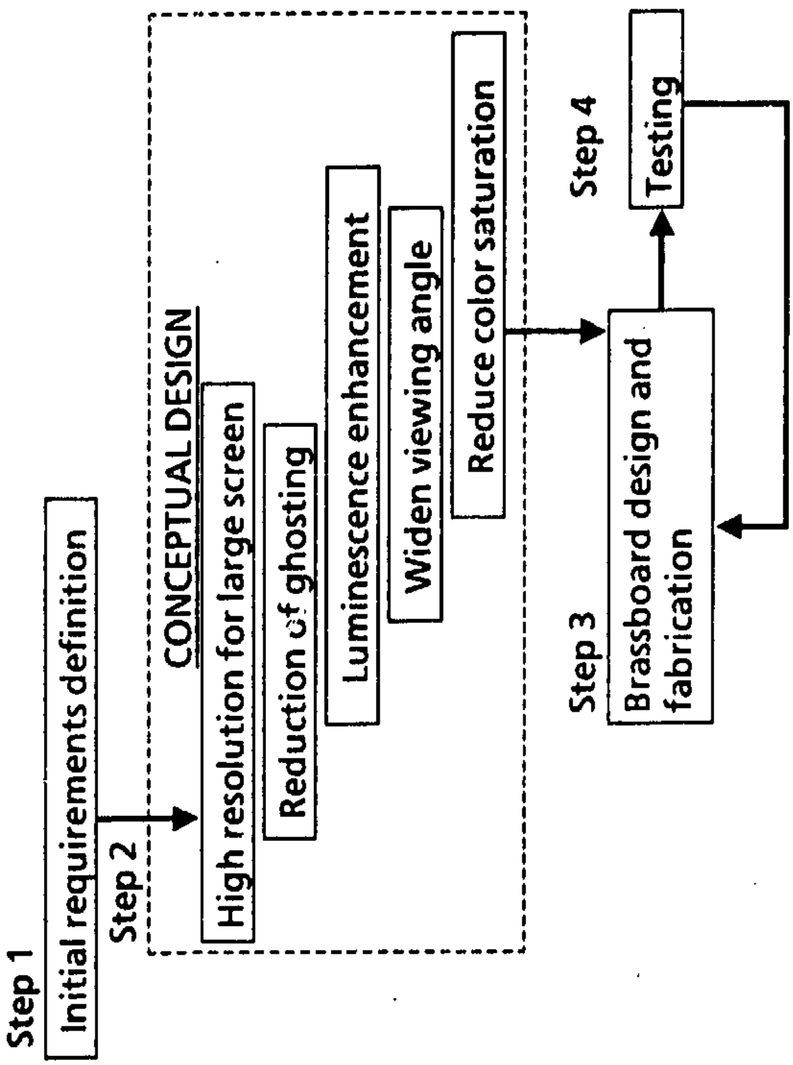

Figure 3.3-1. Logic Flow for High Performance Color Flat Panel LCD Display

3.3.4 Schedule

The major milestones for the development of large high performance color LCD displays are shown in Figure 3.3-2. The three year schedule shown has been derived to support development of the IOC Space Station. Considering a phase C/D start in the third quarter of FY87, the start date for this project must occur fairly soon. Some overlap of phase-C/D will be necessary. Coordination with the current OMV program's ground based workstation development and evolution of that system to a shuttle based workstation is suggested.

3.3.5 Resources

The time phased resource requirements estimated for the LCD flat panel display are shown in Table 3.3-2. The total cost estimate for this plan is approximately $1.2M. This figure includes 10 man-years (@ $120,000/man-year) plus an additional $25K for equipment and materials. This brings the total to $1.225M with the largest portion, $300K, going to the testing. Staffing will grow from two to five people over the course of the program.

3.4 HIGH PERFORMANCE COLOR PROGRAMMABLE MULTIFUNCTION SWITCH

Another application of LCD display elements is in the small display area of a programmable switch. By having the capability to change the function (resulting action) of a switch and the label on it, a single switch can be used for many purposes. This reduces the total number of switches required in the vehicle, saving weight, volume, and wiring complexity. Redundancy can also be achieved at a lower cost penalty.

3.4.1 Descriptions and Benefits

Current programmable multifunction switch technology utilizes light emitting diode (LED) components. However, an LED element switch requires 1-2 watts of power while a similar LCD device requires only 0.1 watts. Considering a typical workstation layout of 500-100 of these switches in each of the five or six habitable modules of the Space Station over a 10-year life, a reduction in requirements of KW can be achieved. Using the estimated cost of power NASA will charge experiments (per KW), a total of $ M in resources can be made available to sell to experiments that originally was needed for basic Space Station systems.

3.4.2 Technical Approach

An overall logic flow for this program is shown in Figure 3.4-1. The numbered blocks relate directly to the steps outlined below. This figure shows the steps involved in

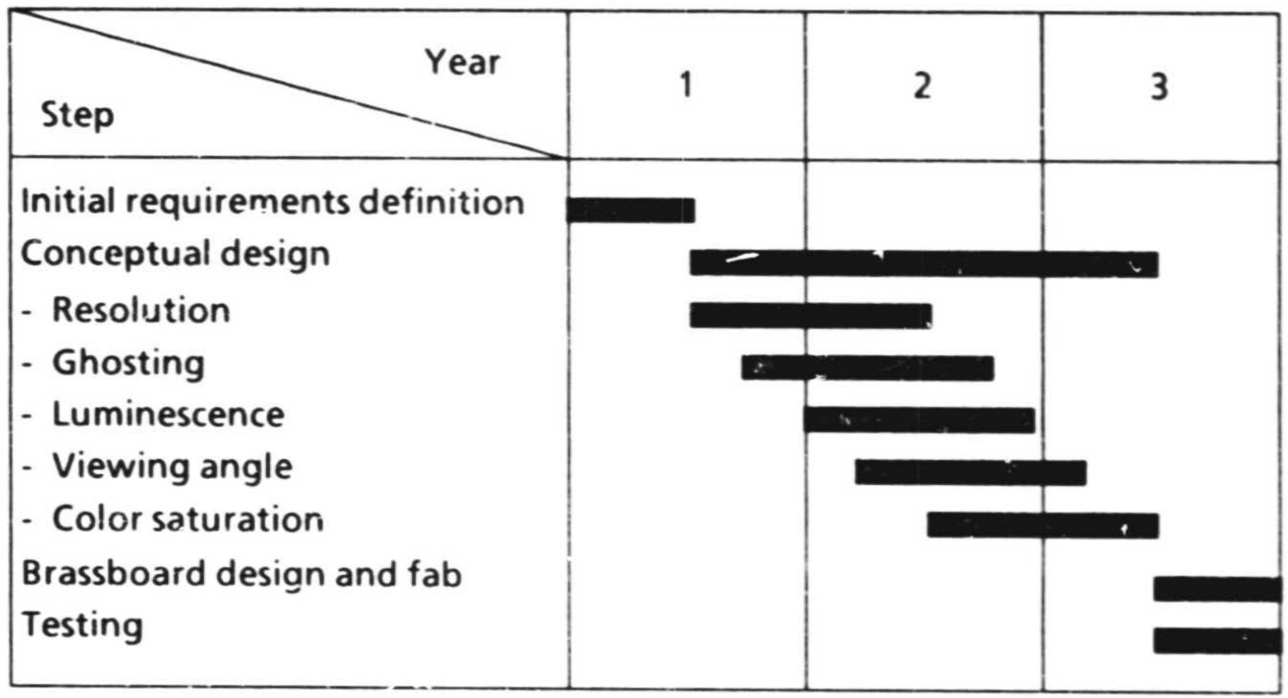

Figure 3.3-2. Schedule for High Performance Color Flat Panel LCD Display

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Step / Year	1	2	3	Total
Initial requirements definition	180			180
Conceptual design				
- Resolution	72	72		144
- Ghosting	36	108		144
- Luminescence		144		144
- Viewing angle		108	36	144
- Color saturation		72	72	144
Brassboard design and fab			205	205
Testing			300	300
Total	288	504	613	1225

Table 3.3-2. Resource Requirements for High Performance Color Flat Panel LCD Display

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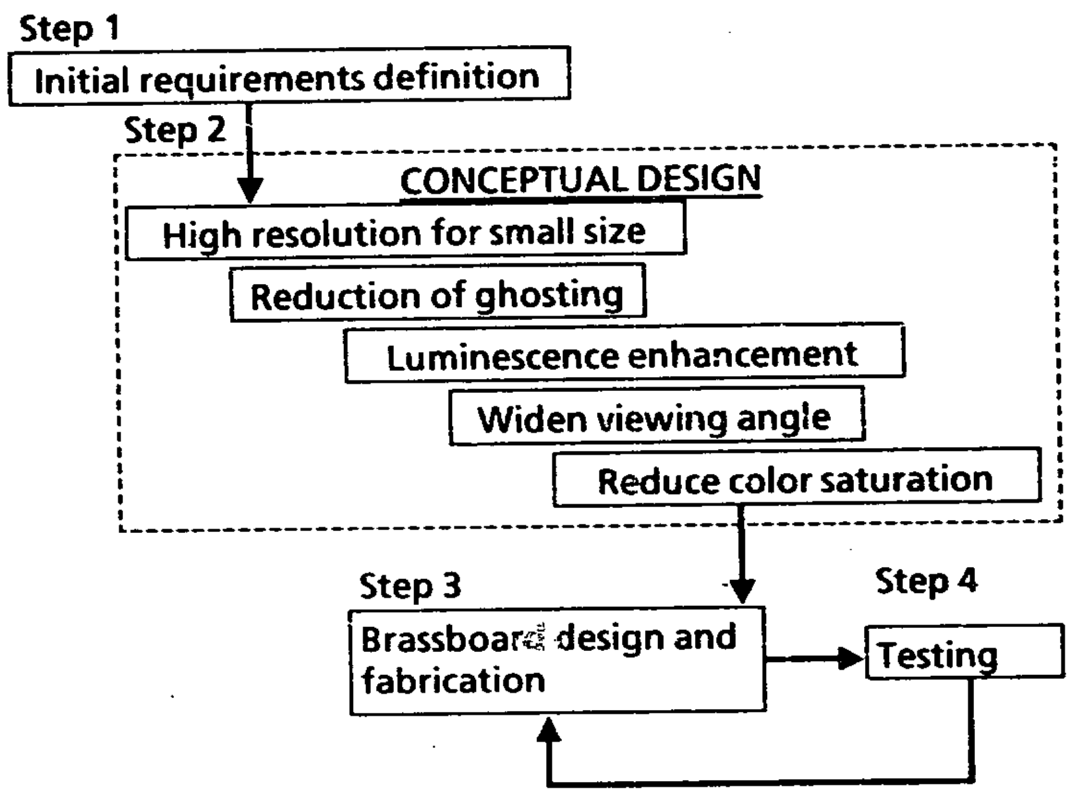

Figure 3.4-1. Logic Flow for Small High Performance Color Programmable Multifunction Switch

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developing a programmable switch device that has resolution, luminosity, and can be viewed at wide angles, but is lower in weight, volume, and power. They describe tasks associated with this technology from initial requirements review, through prototype development, to laboratory evaluation. This program features an overall workstation layout effort combined with a direct effort in the development of large LCD display technology.

STEP 1: Initial Requirements Definition. Functional, operational, and ergonomic requirements for the programmable switch will be established.

STEP 2: Conceptual Design. Investigations will focus on enhancement of current techniques to provide high resolution graphics (80 lines per inch), sufficient luminance (35-50 foot-candle environment), and an increase in color saturation.

STEP 3: Brassboard Design and Fabrication. Includes design and fabrication of a brassboard model.

STEP 4: Testing. Testing of the programmable switch model will be performed in a workstation testbed. Finally, the programmable switch/workstation will be used to evaluate the design using a number of test subjects, performing a variety of tasks requiring programmable switches, with several different workstation layouts.

3.4.3 Facility Requirements and Facility Candidates

Facility requirements to support the recommended developments are as follows: (1) laboratory/shop facilities where a prototype and testbed components can be fabricated, assembled, and checked out, and (2) Space Station multifunction control testbed.

Table 3.4-1 lists the NASA facilities which have capabilities pertinent to the various areas of controls and switch development. Based on this review, no new facilities should be necessary to support these development programs.

3.4.4 Schedule

The three year schedule shown in Figure 3.4-2 has been derived to support development of the IOC Space Station. Considering a phase C/D start in the third quarter of FY87, the start date for this project must occur fairly soon. Some overlap of phase C/D will be necessary. Coordination with the current OMV programs's ground based workstation development and evolution of that system to a shuttle based workstation is suggested.

TABLE 3.4-1
FACILITY CANDIDATES FOR PROGRAMMABLE SWITCH ADVANCEMENT PROGRAM

ID CODE	NASA CENTER AND FACILITY NAME
	MARSHALL SPACE FLIGHT CENTER
4487	Active Optics and Computer Aided Design Laboratory
4708	Checkout Control Complex
4708	Checkout System Electrical Support Equipment
4708	Class 100,000 and Class 10,000 Clean Room
4610, 4663, 4491	Computer-Operated Simulation Facility
4487	Data Systems Test and Development Laboratory
4708	Electrical/Electronics Parts and Components Test Area
4728	Electronic Equipment Development Laboratory
4487	Large-Scale Integrated Circuit Development Laboratory
4487	Optical/Digital Image Processing Facility
4487	Optical Fabrication Shop
4487	Optical Test and Fabrication Facilities
4487	Remote Manipulator Systems R&D Laboratory
4708	Mission Avionics and Control Simulation Facility
4487	Simulation Laboratory, Control System
4487	Electronics Guidance and Control Development Lab
4481	Vibration Isolation Platform Facility
	JOHNSON SPACE CENTER
14	Electro-Optical and Laser Laboratory
16	Simulation Laboratory
9A	Mockup and Integration Laboratory
15	Physical Optics Laboratory
	GODDARD SPACE FLIGHT CENTER
5	Holographic Diffraction Grating Laboratory

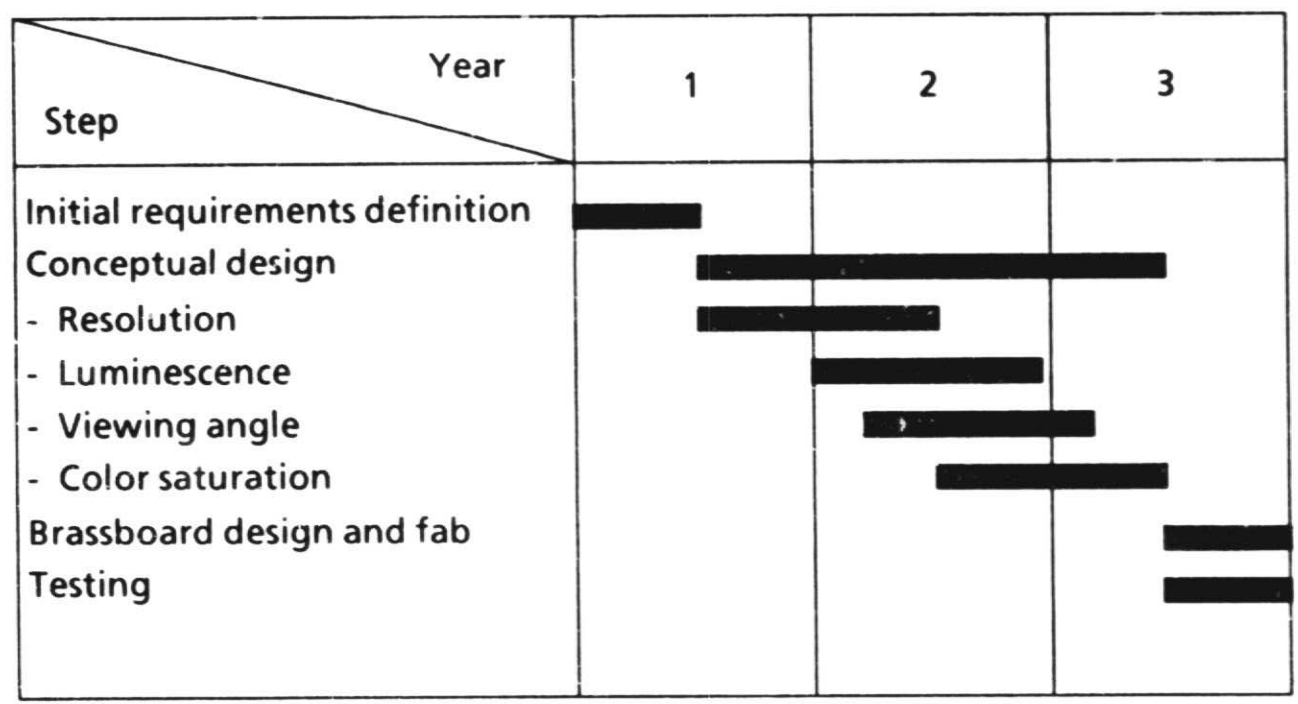

Figure 3.4-2. Schedule for Small High Performance Color Programmable Multifunction Switch

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3.4.5 Resources

The total cost estimate for this plan shown in Table 3.4-2 is approximately $800K. This figure includes 6.5 man-years (@ $120,000/man-year) plus an additional $16.25K for equipment and materials. This brings the total to $796.25 with the largest portion, $195K, going to the testing. This program, being very similar to the previous flat panel study, but smaller and not as demanding in response time performance, has been estimated at 65% of the flat panel study cost.

Year / Step	1	2	3	Total
Initial requirements definition	117			117
Conceptual design				
- Resolution	46.8	46.8		93.6
- Luminescence		93.6		93.6
- Viewing angle		70.2	23.4	93.6
- Color saturation		46.8	46.8	93.6
Brassboard design and fabrication			133.25	133.25
Testing			195	195
Total	187.2	327.6	398.45	796.25

Table 3.4-2. Resource Requirements for Small High Performance Color Programmable Multifunction Switch

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